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THE FOULNESS MULTITON AIR BLAST SIMULATOR. PART 3. BLAST WAVE F--ETC(U)
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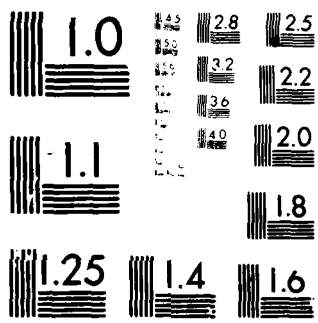

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(6) The Foulness Multiton Air Blast Simulator. Part 3, Blast Wave Formation and Methods Used to Drive the Simulator,

(12) 34

(11) Mar 80

(10) Pamela M. Clare

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CONTENTS

1. INTRODUCTION

The 4.9 m (16 ft) diameter nuclear air blast simulator has been described in detail in Parts 1 and 2 (1,2). Part 2 reported that an efficient method of driving the simulator was to detonate a helical charge of detonating fuse (Cordtex or Superflex) in the 1.8 m (6 ft) diameter section of the tunnel. Since then a study has been made of the mechanisms by which blast waves are generated from this type of charge. This was done in order to obtain a better understanding of the principles involved, thus enabling a greater degree of control to be exercised over the waveform produced, and to give an indication of how the waveshape and positive duration of the blast wave might be improved. The problem of producing low pressure blast waves with long positive duration has been overcome by immersing the charge in aqueous foam sited in the firing chamber. Irregularities in waveshape in the medium pressure range have been greatly reduced by modifying the blast wave shape by means of an aqueous foam plug positioned between the 1.8 and 4.9 m diameter sections.

2. THE EXPLOSIVE DRIVER

The explosive driver is sited in the 1.8 m diameter section of the tunnel, a sketch of which is given in figure 1. The charge consists of Cordtex/Superflex wound on to 300 mm (1 ft) diameter hollow formers of varying length, which are suspended axially from eyebolts fixed to the roof of the tunnel.

2.1 The blast field produced by a helical charge of detonating fuse

Consider first the blast wave produced by a line of Cordtex. Experiments have been carried out in which a 3.7 m (12 ft) length of Cordtex was detonated in free air, and the peak overpressure, positive phase duration and shock front arrival time were measured at distances between 0.1 and 0.5 m from the charge (3). These data, together with a knowledge of the detonation velocity, enable the shock front profile from a line charge to be drawn, and this is shown in figure 2. Now suppose that the line charge of Cordtex is to be wound as a helix. Figure 3 shows how the bow wave produced by the line charge follows round the turns of Cordtex along the helix. In effect, radial shocks are generated sequentially from A, B, etc, as the detonation head passes along the Cordtex and the shock generation from each element of Cordtex is a continuum. The inward-going shocks are modified by former material. The outward-going blast wave is modified by the pitch of the Cordtex; when the turns of Cordtex are close together, the shock waves from successive turns will catch up and reinforce the first expanding shock wave since the velocity of shock fronts moving in a shocked medium increases. The direction of propagation is more nearly normal to the helix axis when the turns of Cordtex are close together than when they are far apart. When the helix is detonated inside the 1.8 m (6 ft) diameter section of the blast tunnel the outward-going shock arrives at the wall and is reflected back towards the axis; the factors influencing the rate of travel of the shock back across the tunnel are rather complex. Near the wall, the shock strength will increase after reflection, but it will then be travelling against the flow which will slow it down. Near the centre of the tunnel, it will be travelling through a heated medium which will increase the velocity. Measurements made from pressure transducers mounted in the walls of the tunnel and along the axis of the tunnel showed that, apart from the first axial pulse, all subsequent pulses are those produced by wall reflections. Once detonation is completed, the pressure gradient produces axial propagation down the tunnel. The reflected wall shocks

rapidly catch up the first axial pulse to form eventually a plane wave front. Figure 4 shows the sequence of events taking place as the blast wave is formed from a tunnel-fired helix of Cordtex.

2.2 The blast wave shape

The effect on impulse of varying the former length for different winding pitches and former materials is shown in figure 5. First, we see that for a given type of former and former length, the impulse increases as the pitch decreases since a greater amount of Cordtex is accommodated for the shorter pitch. Second, for a given pitch, for example 248 mm (9¾ in.), a much greater impulse is developed by the use of expanded polystyrene when compared with the same charge wound on various types of metallic former. At this stage it was useful to carry out a comparative study of the energy release from various charge configurations, and a separate experiment was conducted in which samples of such charges were fired in a hollow steel 1.8 m (6 ft) cube. Pressure transducers mounted in the walls of the chamber were used to record the pressure-time histories resulting from the detonation. It was found that a typical pressure excursion consisted of an initial spike followed by a steady overpressure which lasted for several tens of milliseconds. The steady state pressure was used to calculate the energy release from the expression $E = PV/(\gamma - 1)$. These results show, in figure 6, that the expanded polystyrene is contributing significantly to the energy release.

The importance of the contribution of the expanded polystyrene former to impulse is further illustrated in figure 7 which is a plot of impulse versus former length. The results for two different lengths of Cordtex are given, each length being detonated using three different pitches. The figure shows that doubling the amount of expanded polystyrene (or former length, when the pitch is doubled) increases the impulse by approximately 75%. Also included are the results obtained using "inert" metallic formers; comparing the results for a given pitch for the same charge length (30.5 m Cordtex at 248 mm pitch), it is noted that the use of expanded polystyrene doubles the impulse.

The energy enhancement produced by the use of expanded polystyrene, as described above, may also be utilised to tailor the waveform. Approximately the same impulse can be obtained for two peak pressure values by winding Cordtex on polystyrene formers with different pitches. This is illustrated in figure 8 where the extra energy contributed by the longer former of the 248 mm (9¾ in.) pitch is compensated by the extra explosive weight associated with the smaller pitch, shorter charge length. Examination of the charge arrangement shows that the higher peak pressure blast wave would be produced using a greater amount of Cordtex (and less expanded polystyrene) than the lower pressure blast wave (48.2 m Cordtex wound at 102 mm on a 3.3 m long former compared with 30.5 m Cordtex wound at 248 mm pitch on a 7.8 m former).

2.3 The blast wave peak overpressure

So far, we have only considered the effect of expanded polystyrene on impulse. Figure 9 shows the variation in peak overpressure that can be achieved by varying the length of polystyrene former for a 30.5 m (100 ft) length of Cordtex fired using different pitches. Doubling the amount of expanded polystyrene increases the peak overpressure by about 25%. The results obtained using an "inert" former are also shown. Comparing these "inert" results with

those for expanded polystyrene and the same charge geometry (248 mm pitch) we see that for the expanded polystyrene case, the peak pressure has been increased by 25%. Similarly, consider now the 102 mm pitch expanded polystyrene results, the peak pressures are the same value as the inert former data although the helical lengths are different, ie, the pitch of itself has little effect on the peak pressure, and again we must conclude that the extra energy release is a function of the extra expanded polystyrene.

3. THE USE OF AQUEOUS FOAM PLUGS TO SMOOTH IRREGULARITIES IN WAVESHAPE

Various aspects of the tunnel geometry such as the expansion cones between the 1.8 and 2.4 m diameter sections, the 2.4 and 4.9 m diameter sections and the tunnel baffle arrangements generate rarefactions and other irregularities in the blast waveshape. This problem can be minimised by the use of an aqueous foam plug sited between the source of the irregularity and the 4.9 m diameter test section.

3.1 Irregularities produced before blast wave arrival in the 4.9 m diameter test section

Irregularities introduced into the blast wave by the geometry of the 1.8 m diameter section are significantly reduced by siting a plug of aqueous foam in the 2.4 m diameter section. When the blast wave enters the foam it is modified by energy being transferred to the foam, breaking it into droplets which are accelerated and heated by the gas flow. Figure 10 illustrates the technique and the smoothing effect on the waveshape received in the 4.9 m diameter test section. The comparison has been made on a peak overpressure basis, the charge geometry for the foam case being adjusted to compensate for the attenuation of the peak overpressure by the foam.

3.2 Irregularities produced by the baffle at the end of the tunnel

The existing reflection eliminator technique consists of a concrete wall stood off from the end of the tunnel by 1 m. Although this arrangement is reasonably efficient in reducing the magnitude of the reflection and rarefaction produced at the tunnel termination, they arrive back in the test section 180 ms after the first shock and the rarefaction prematurely reduces the value of the positive duration; this is most apparent for blast waves with a peak overpressure of 40 kPa (5.8 psi) or less. The reflection may be eliminated and the rarefaction considerably reduced by the use of an aqueous foam plug sited in front of the concrete wall. Figure 11 shows the arrangement whereby foam has been introduced into a large polythene bag. The foam attenuates the blast wave before arrival at the concrete wall, thus eliminating the reflection normally received in the 4.9 m diameter test section and reducing the value of the rarefaction. The value of the positive duration is increased by about 10%. The technique would be particularly useful when applied to low pressure blast waves, where the baffle termination causes a most abrupt termination to the positive phase (figure 12). Such a rapid change of pressure with time could have a significant effect on certain types of sensitive target response work, eg, glass.

4. IMMERSION OF CHARGE IN AQUEOUS FOAM TO PRODUCE LOW PRESSURE LONG DURATION BLAST WAVES

4.1 Immersion of the charge in foam

Any attempt to produce a long duration blast wave of less than 7 kPa (1.0 psi) in the 4.9 m diameter test section, simply by reducing the length of

Cordtex used in the helical charge, results in a substantial reduction in positive duration. The problem has been overcome by firing a larger charge immersed in aqueous foam. Figure 13 illustrates the technique and gives examples of the waveshapes produced at a given peak overpressure compared with those obtained by firing small charges without foam. With this arrangement a large proportion of the energy of the charge is absorbed by the foam. In addition to the liquid being accelerated, and thereby acquiring kinetic energy, some of the liquid in the foam is heated and vaporised. In order to compensate for the energy absorbed a larger charge than that used in the foam plug case was necessary. Figures 14 and 15 show comparisons between pressure-time profiles recorded at locations along the tunnel with and without the use of foam. The pressure variations recorded in the driver section when the charge is surrounded by foam are modified considerably. The overall effect is an attentuation in the pressure obtained; the period of the pressure fluctuation superimposed on the gradually increasing pressure waveform was doubled in the foam case. This is due to the reduced strength of transverse shocks coupled with the lower wavefront velocity which occurs in liquid suspensions. It can also be seen that the fluctuations are more rounded and this is due probably to relaxation processes (the acceleration of the droplets and heat transfer between the gases and the liquid will take a finite time). Figure 16 shows the ratio of peak overpressure with foam to that without foam as a function of distance from the end door. For the transducers mounted in the tunnel wall opposite the helix, the pressure is reduced to 25% of the value without foam. Beyond the end of the helix, where the axial shock moves off into the foam, the pressure is reduced to about 14% of the value without foam. When the blast wave enters the 2.4 m (8 ft) diameter section, pressure is reduced to about 2 to 3% of the value without foam and remains around this level throughout the remainder of the tunnel, while the positive duration is only reduced by about 20%, thus making it possible to generate low pressure long duration blast waves.

4.2 Comparison of low pressure blast waves with Brode's (4) theoretical pressure-time profiles for TNT

Figures 17(a) to (e) show examples of pressure-time profiles produced using either Cordtex or Superflex at various pitches immersed in foam. Superimposed on each profile is Brode's theoretical pressure-time profile for TNT for the appropriate shock peak overpressure. The Brode profiles have been impulse scaled to those in the blast tunnel. The nearest fit is obtained using 122 m (400 ft) Superflex with a 140 mm ($5\frac{1}{2}$ in.) pitch. The equivalent yield corresponding to the blast tunnel pressure-time profiles is obtained by cubing the ratio of the tunnel impulse to that from a 908 kg (2000 lb) charge fired in free air for a given peak overpressure. This gives the equivalent free air charge in short tons of TNT. The equivalent yield for each profile has been calculated and the yields range from 30 to 115 tonnes TNT. Reference to figures 13(a) and (b) shows that the yield has been increased by factors of about 100 and 50 respectively for the foam immersed charge. Since only about 50% of the total energy of a nuclear explosion is released as blast, it follows that a 1 kton nuclear explosion in free air is equivalent to 0.5 kton of TNT in free air. Alternatively, had the nuclear explosion been a surface burst, then the blast produced would be roughly the same as that from 1 kton of TNT in free air. It is seen therefore that the equivalent yield defined above may be considered to be the mass of TNT fired in free air, or the yield of a nuclear explosion on the ground surface that would produce the measured blast profile. It is evident that the blast tunnel waveforms could represent those from yields greater than 115 tonnes of TNT over a limited

time period. In figure 18 a theoretical profile is matched to blast waves produced in the tunnel; in one case a profile is fitted to the decaying pressure over 175 ms and in another to the first 60 ms of the pressure-time plot. For these two cases the equivalent yield of TNT, which would produce these waveforms, would be 0.46 and 1.3 kton respectively. Providing that the target being tested responded before the blast wave produced in the tunnel departed from the ideal waveform, then the simulation would be adequate.

5. EXPERIMENTAL DETAILS OF AQUEOUS FOAM TECHNIQUES

The foam is produced using an Angus Turbex generator, which is a standard fire-fighting equipment. The foam is held in place in the 1.8 or 2.4 m diameter sections by means of polythene diaphragms which are assembled in around 2 h. The polythene bag technique used as a reflection eliminator takes rather longer since polythene sheets have to be joined with PVC tape to incorporate the inlet and outlet tubes and also allow for the size of the bag itself. The foam insertion for all three techniques takes a few minutes. The foam expansion ratio (the ratio of the volume of foam to the volume of liquid it contained) was taken by weighing a sample of foam which was extracted from the tunnel foam entry port before closure. It is thought that not a great deal of confidence may be placed in the figures obtained, since the values may not be representative of the foam further along the tunnel.

6. COMPARISON WITH MULTITON AND NUCLEAR BLAST WAVES

6.1 Comparison of techniques

The practical implications of varying charge, former length and material, and the use of foam are shown in figure 19. Profiles (a) and (b) have the same approximate peak pressure, but vastly different impulses, the latter being wound on a polystyrene former, while profiles (b) and (c) have the same impulse for different explosive lengths and former material. Also shown is a multiton profile for the same peak pressure as (a) and (b) to give an idea of the relative multiton simulation. Curve (b) is not a particularly desirable waveform; however, the foam plug technique can be used to smooth out the waveform to a more desirable shape as illustrated by curve (d). The pressure-time profile which most closely matches the multiton or 1 kton nuclear waveshape has a relatively high impulse value for a given peak overpressure, and the optimum conditions for producing this type of blast wave in the blast tunnel are provided when using a low density charge, viz, helical Cordtex with a large pitch wound on an expanded polystyrene former, the waveform being improved by the use of the aqueous foam plug technique.

6.2 Direct comparison with multiton and 1 kton nuclear shots

Figures 20 and 21 compare the blast tunnel pressure-time profiles in the 4.9 m diameter section with those from the 500 ton Suffield and a 1 kton nuclear shot (HOB = 242 m (793 ft)). At lower peak pressure values, aqueous foam has been used to improve the profile by reducing the decay rate over the first 100 ms of blast wave. Figure 20(a) shows the type of profile produced by an "inert" former such as copper. Again, it is seen how the profile may be tailored by using a combustible former, and how the simulation of a pressure-time profile from a multiton shot involves a combination of techniques rather than a simple firing of an axially placed charge of HE. Extra energy can be supplied during the

detonation process and then it is necessary to reduce the decay rate by the use of the foam plug technique for the lower peak pressure range. Limitations consequent upon tunnel geometry still exist, but may be overcome, as already outlined, by further foam techniques. In general, the blast tunnel performance compares well with the multiton results, but more work needs to be done in improving the positive duration and impulse, and at the same time the waveshape.

7. CONCLUSIONS

The waveshape of the blast tunnel profile is a function of fixed tunnel geometry, the explosive driver and the use of aqueous foam. Using the latter two variables, the optimum performance, in terms of blast waves which match multiton TNT or kiloton range nuclear shots, is produced by firing a distributed explosive charge which produces a low energy release per unit volume in the 1.8 m diameter section. The energy release of the charge is increased significantly by winding the charge on hollow expanded polystyrene formers. Aqueous foam has been used to minimise irregularities in the shape of the pressure-time profile, either before the blast wave has arrived at the 4.9 m diameter test section, or as a baffle reflection eliminator device when it is sited at the end of the blast tunnel in front of the baffle.

8. ACKNOWLEDGMENTS

The author would like to acknowledge the support given to this work by members of the Instrumentation and Air Blast Sections of AWRE, Foulness.

REFERENCES

1. Pamela M Clare and R D Rowe: "The Foulness Multiton Air Blast Simulator. Part 1: Early Development - the Gun Driven Facility". AWRE Report O31/74

2. Pamela M Clare: "The Foulness Multiton Air Blast Simulator. Part 2: Recent Developments - The Linear Charge Driven Facility". AWRE Report O4/78

3. R D Rowe: Private Communication

4. H L Brode: "A Calculation of the Blast Wave from a Spherical Charge of TNT". RM A65 (AD 144302) (August 1957)

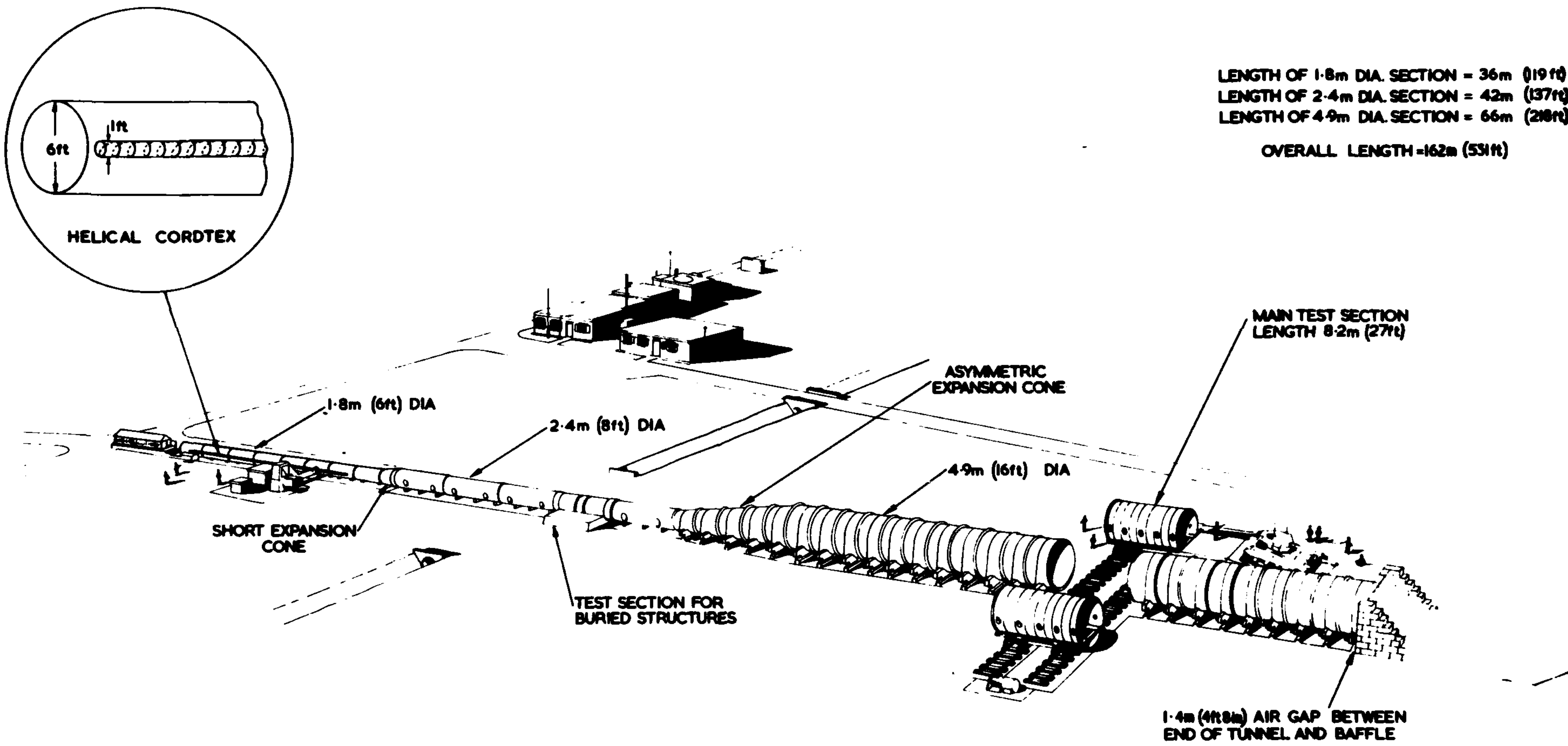


FIGURE 1. GENERAL VIEW OF THE 4·9m (16ft) DIAMETER BLAST TUNNEL

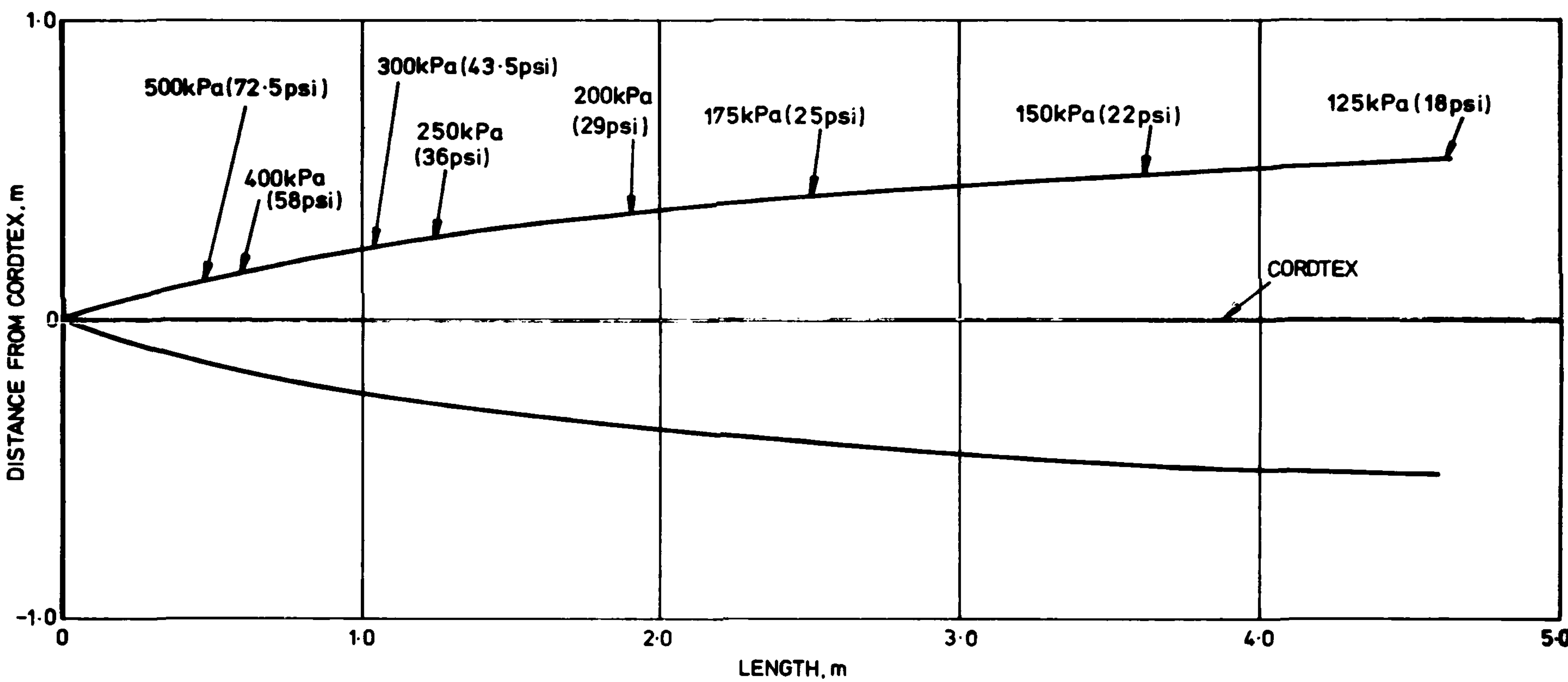


FIGURE 2. SHOCK PROFILE DURING DETONATION OF A LINE OF CORDTEX IN FREE AIR

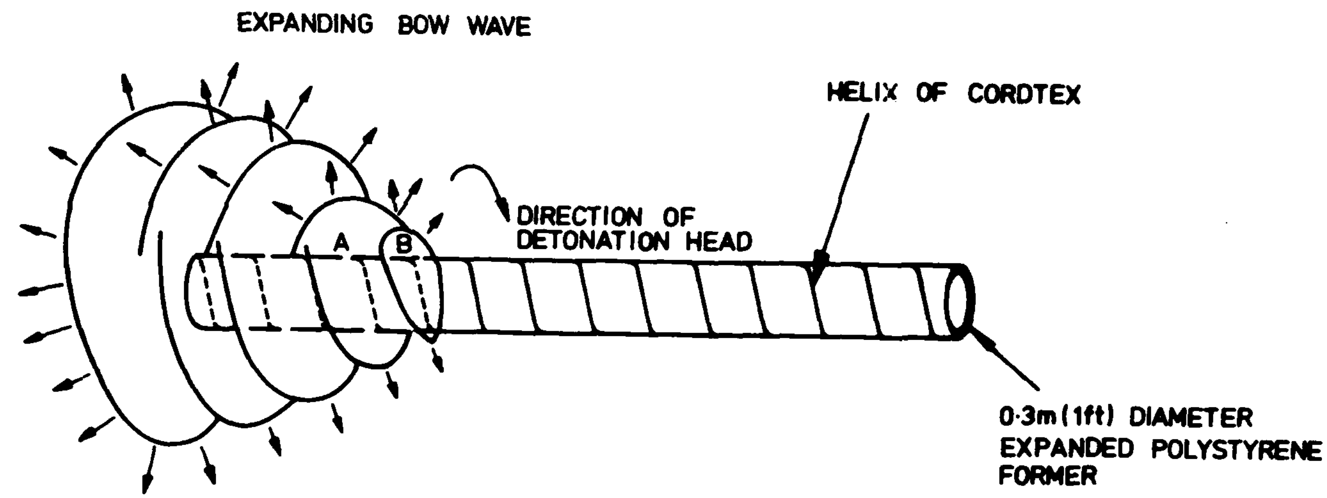


FIGURE 3. SKETCH TO SHOW DEVELOPMENT OF THE BLAST FIELD WHEN CORDTEX IS WOUND AS A HELIX

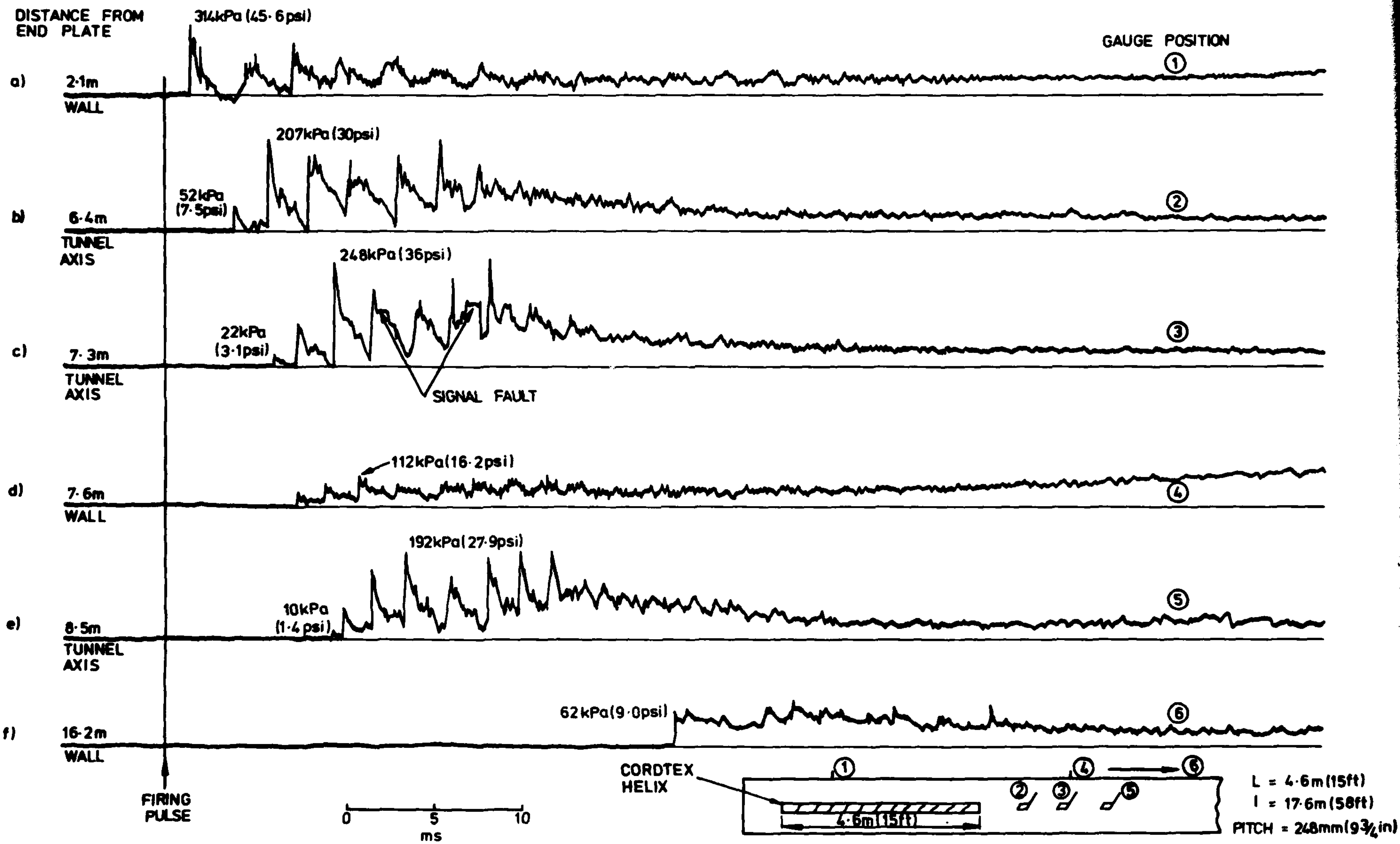


FIGURE 4. WAVESHAPE FORMATION FROM TUNNEL FIRED HELIX

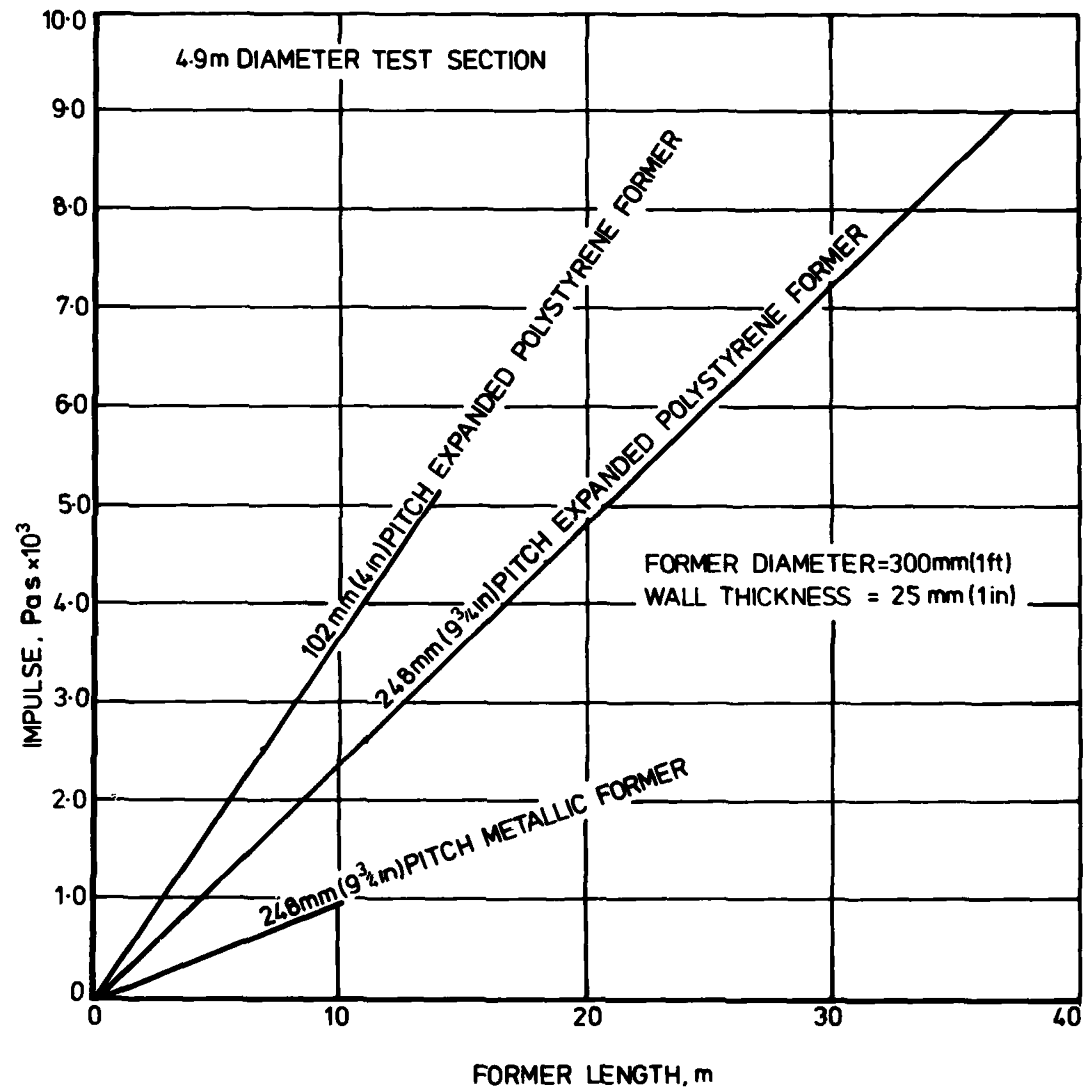


FIGURE 5. EFFECT ON IMPULSE OF VARYING FORMER LENGTH, FOR DIFFERENT PITCHES AND FORMER MATERIAL

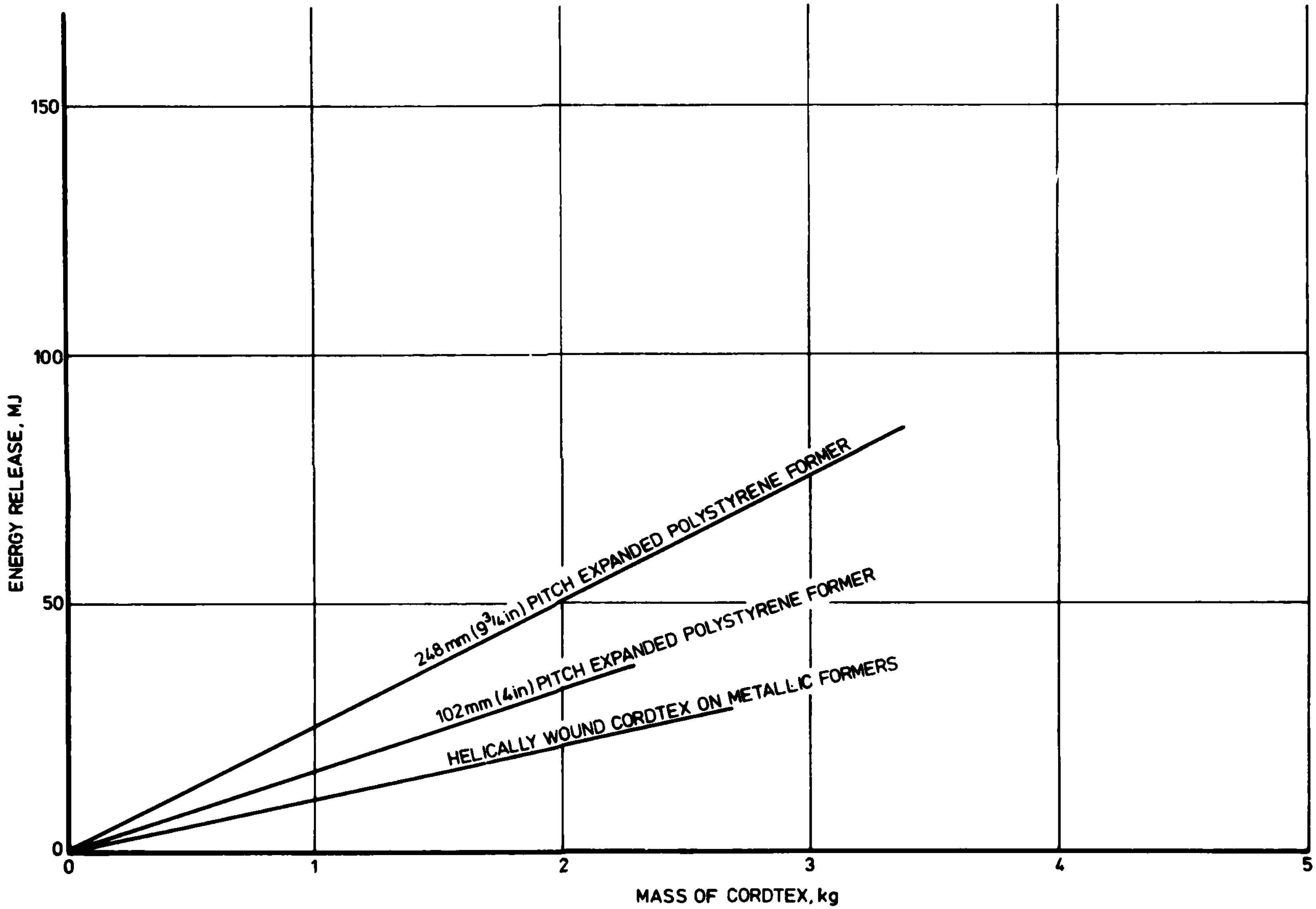


FIGURE 6. COMPARISON OF ENERGY RELEASE IN THE 1·8m (6ft) CUBE FROM THE DETONATION OF VARIOUS CHARGE GEOMETRIES

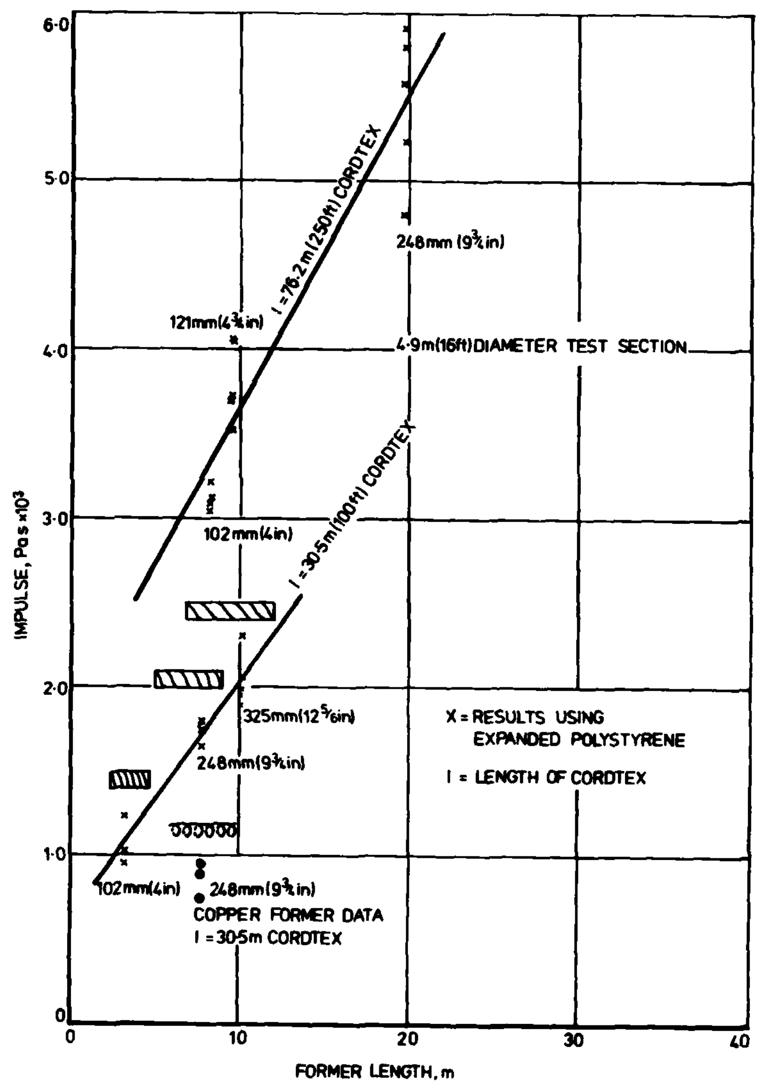


FIGURE 7. EFFECT ON IMPULSE OF INCREASING THE PITCH FOR A GIVEN LENGTH OF CORDTEX

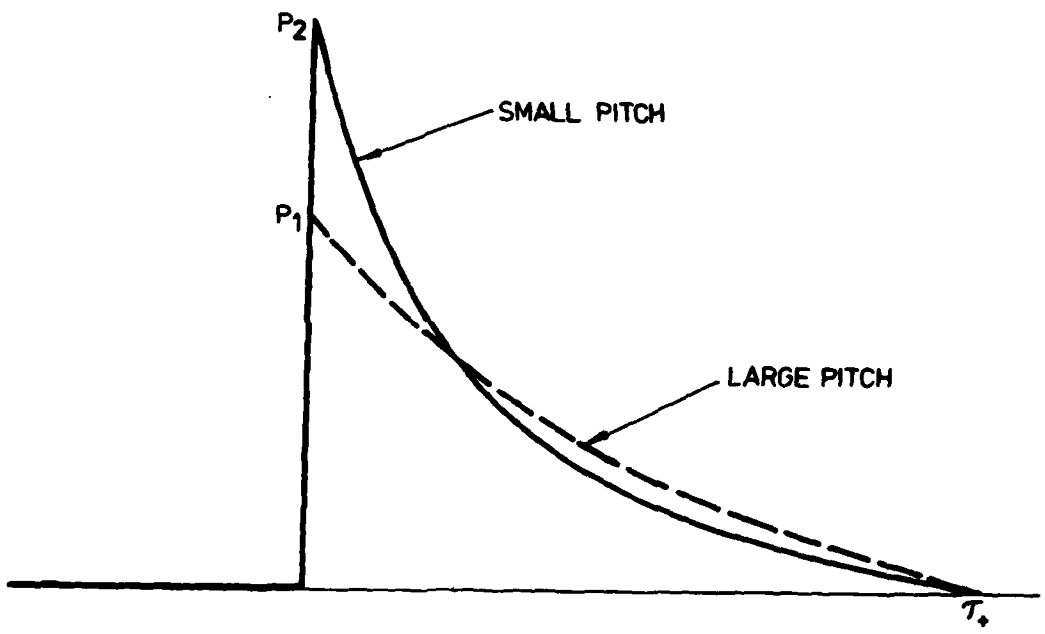


FIGURE 8. SKETCH SHOWING THE PRESSURE DIFFERENCE FOR TWO BLAST WAVES WITH THE SAM
IMPULSE WHICH HAVE BEEN PRODUCED BY THE SAME ENERGY RELEASE

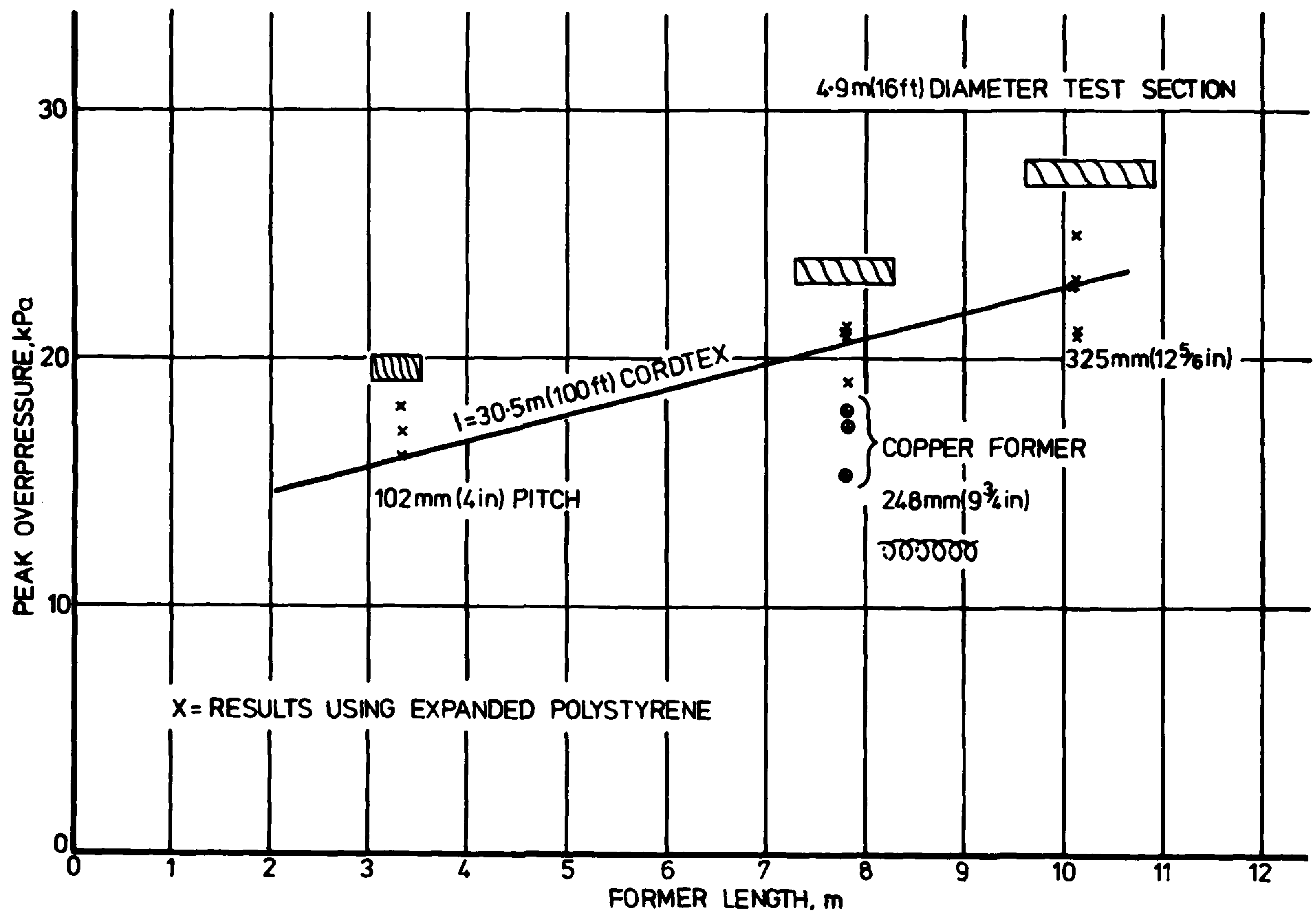


FIGURE 9. EFFECT ON PEAK PRESSURE OF INCREASING THE PITCH FOR A GIVEN LENGTH OF CORDTEX

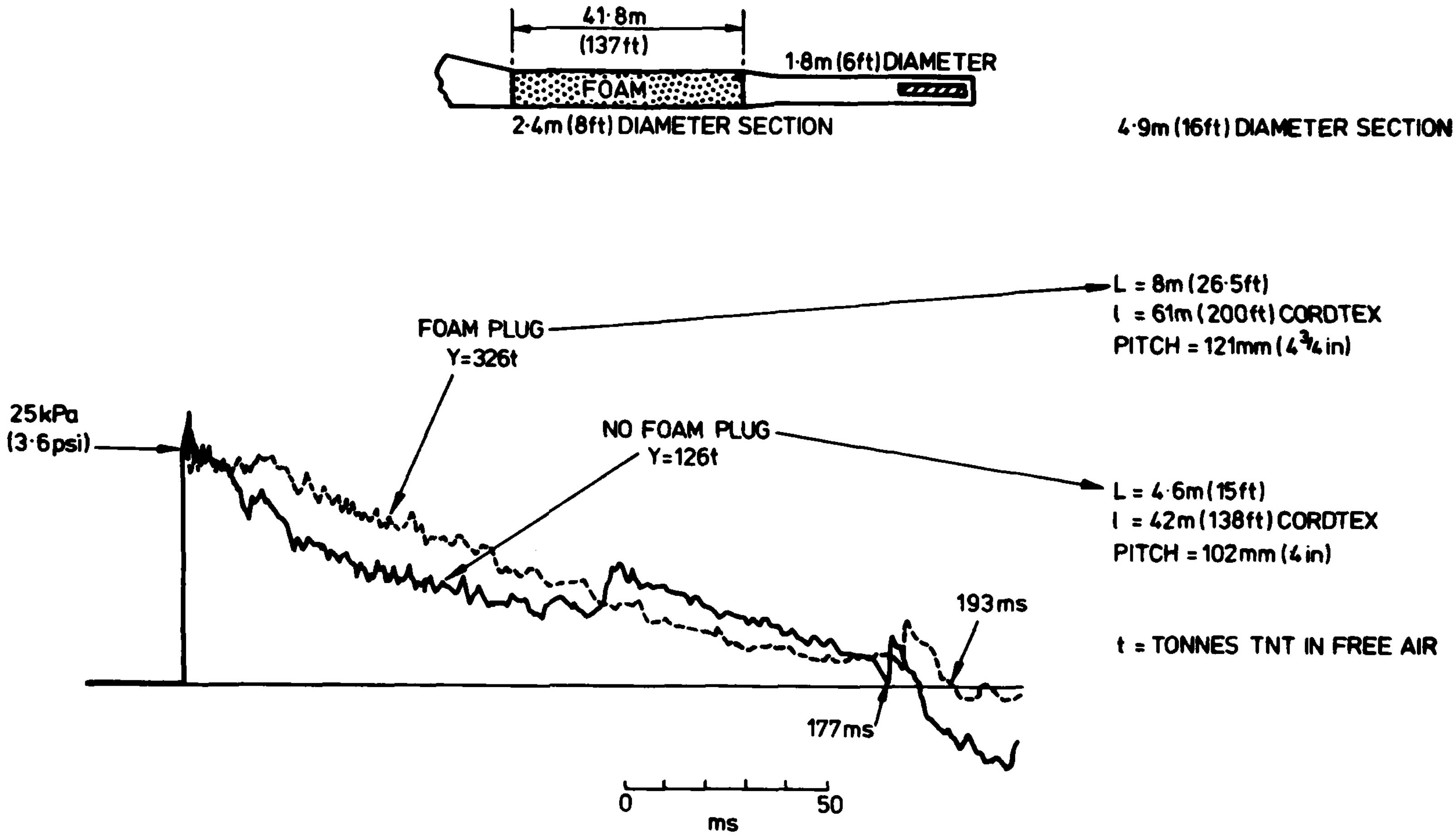


FIGURE 10. SMOOTHING EFFECT ON WAVESHAPE OF SITING FOAM PLUG IN THE 2·4m (8ft) DIAMETER SECTION

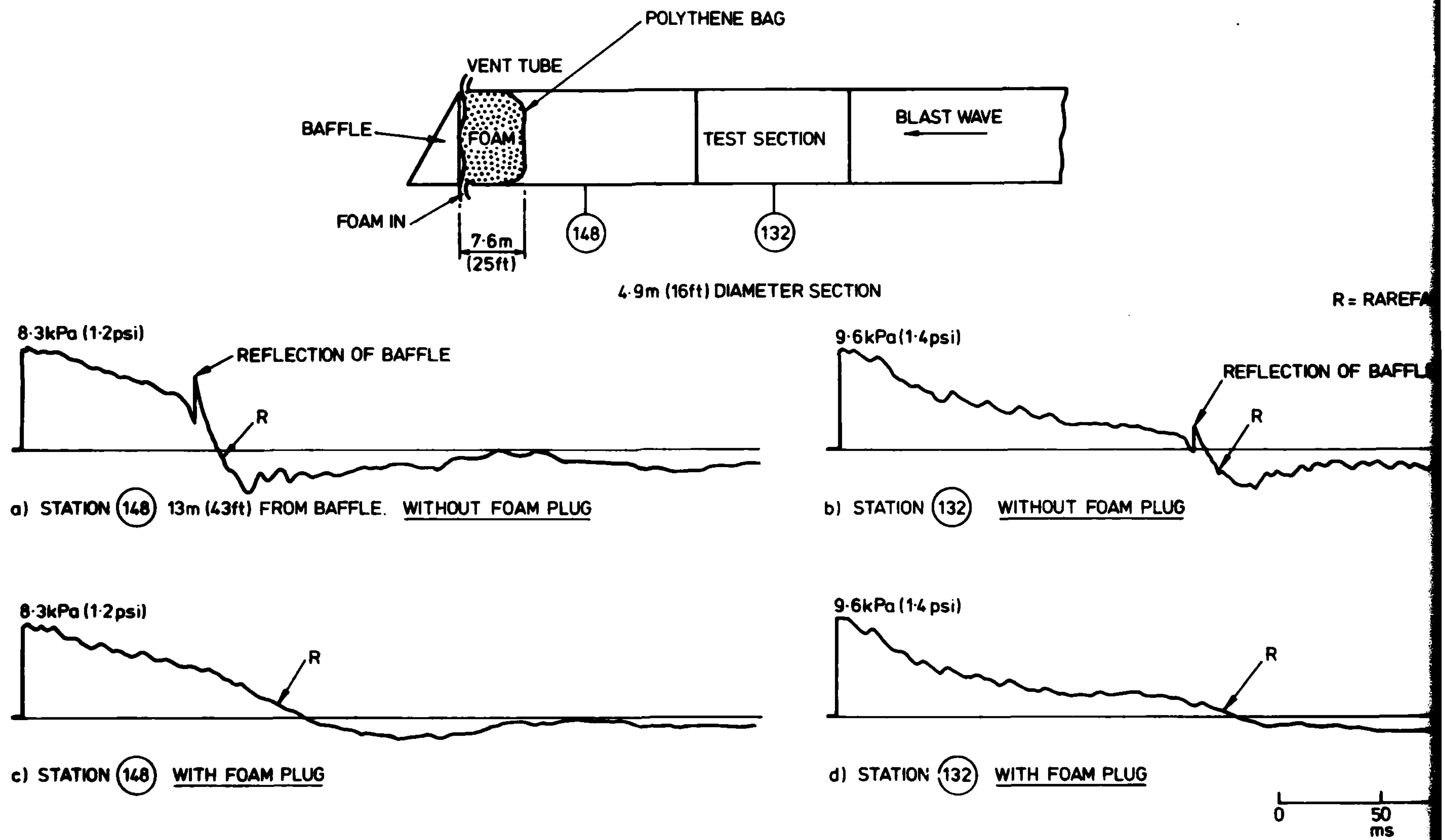


FIGURE 11. PRESSURE - TIME PROFILES OBTAINED WITH AND WITHOUT USE OF FOAM AS A REFLECTION ELIMINATOR

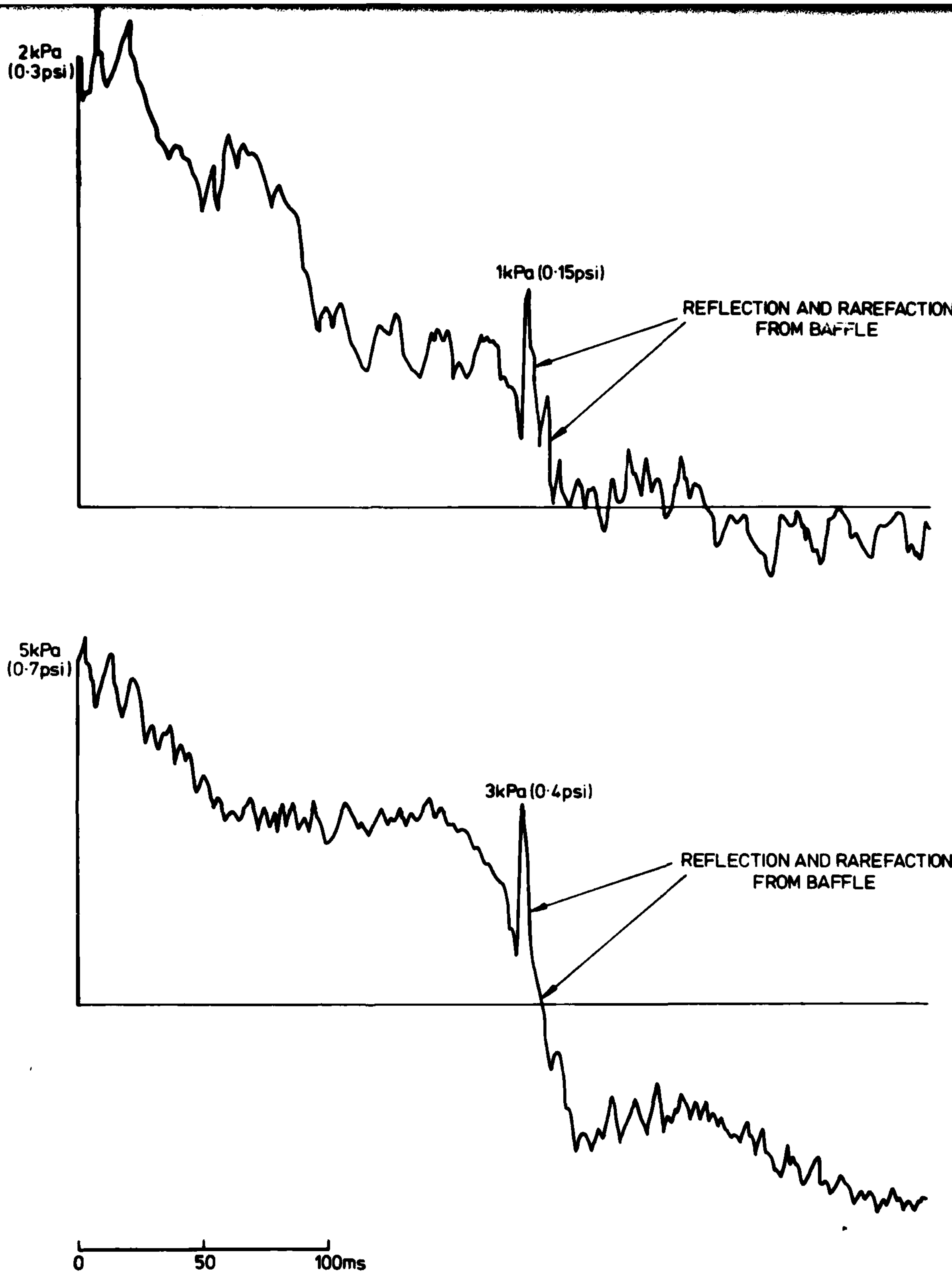


FIGURE 12. LOW PRESSURE BLAST WAVES SHOWING THE MAGNITUDE OF THE BAFFLE EFFECT

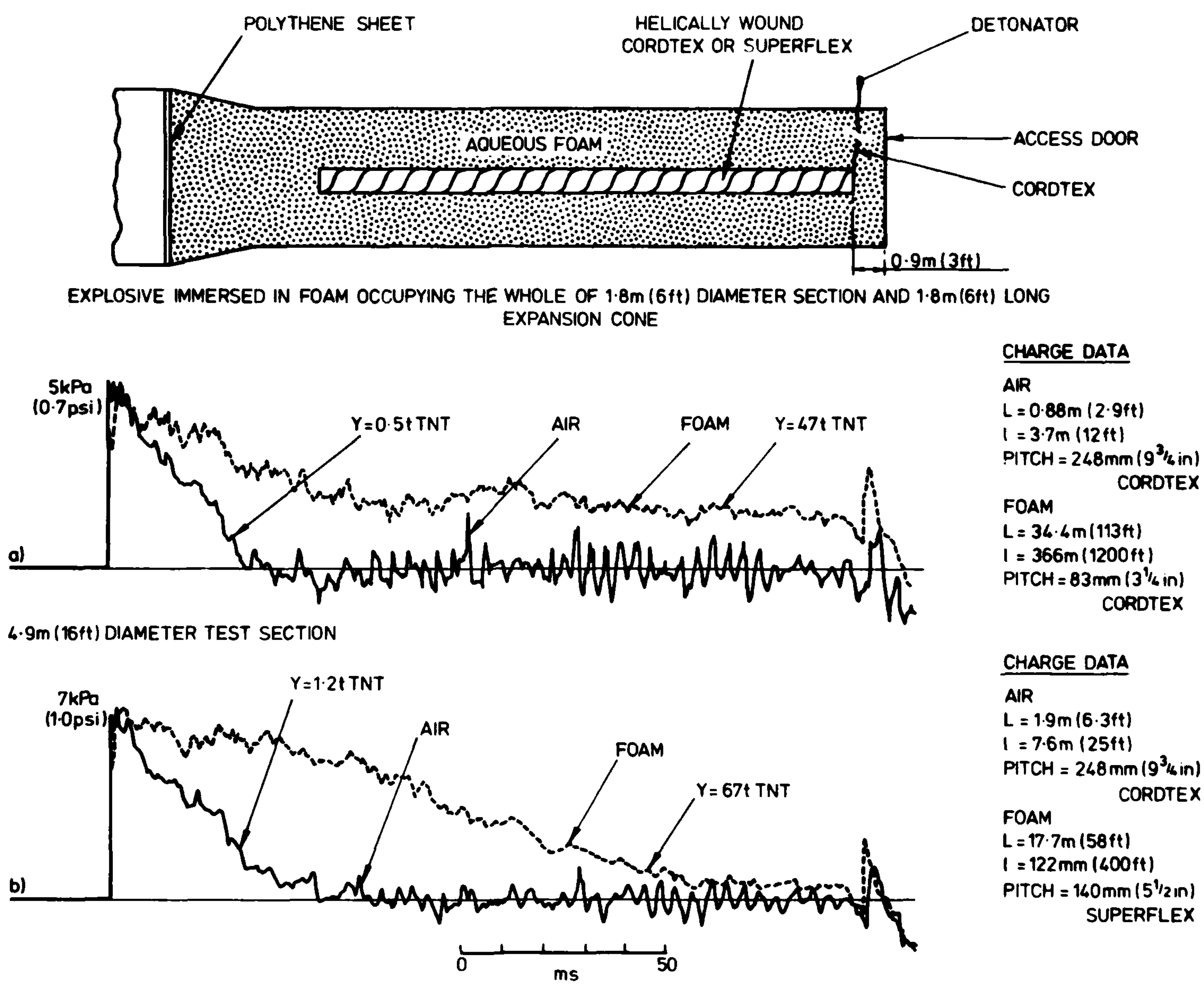
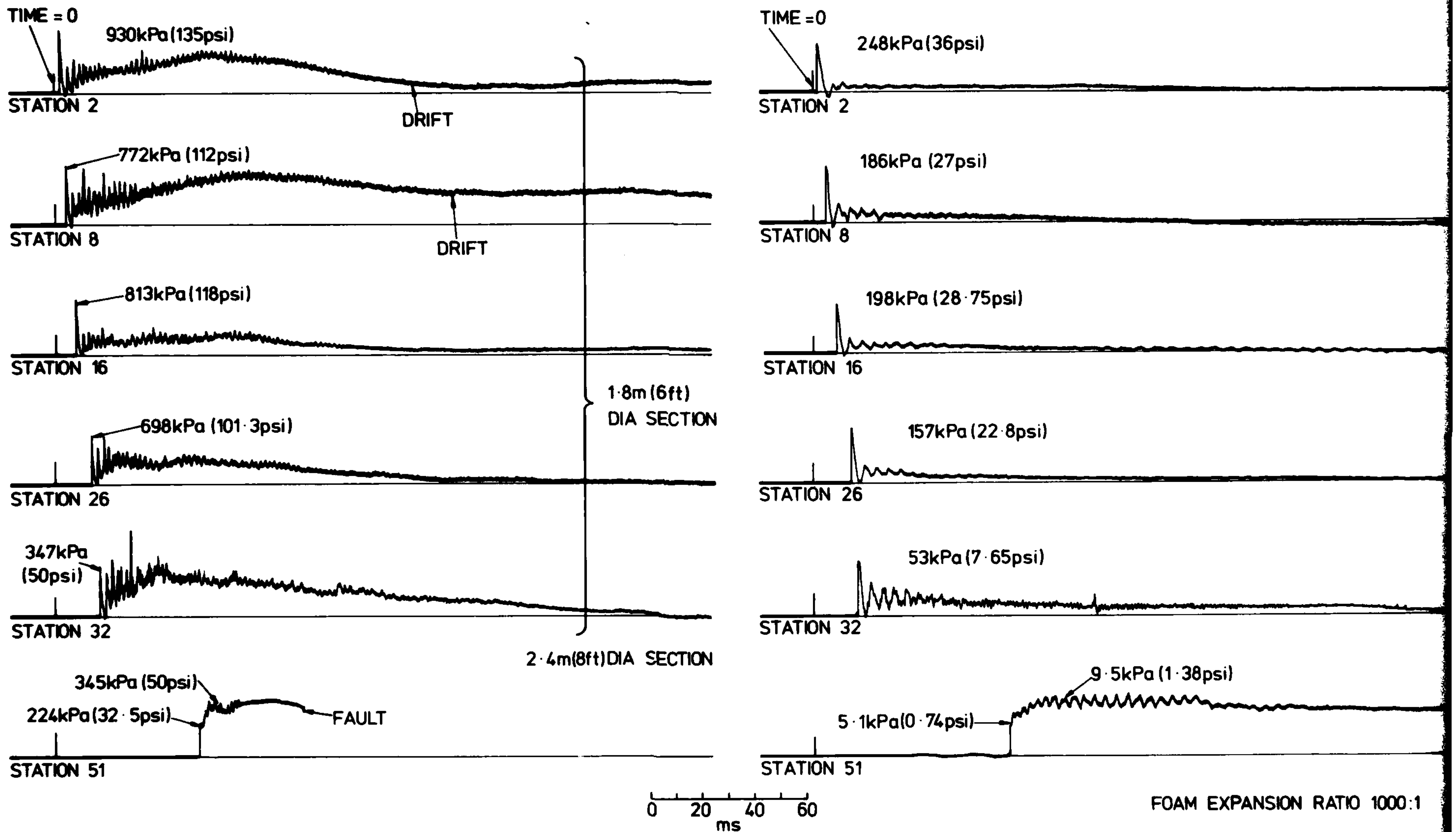


FIGURE 13. COMPARISON OF PRESSURE-TIME PROFILES PRODUCED FOR TWO GIVEN OVERPRESSURE LEVELS WHEN FIRING IN AIR AND WHEN FIRING USING A FOAM IMMERSED CHARGE



L = 30·5m(100ft) l = 91·5m(300ft) SUPERFLEX PITCH = 325mm ($12\frac{5}{6}$in)

a) WHEN CHARGE WAS FIRED IN THE TUNNEL IN AIR b) WHEN CHARGE WAS FIRED SURROUNDED BY FOAM

FIGURE 14. PROFILES OBTAINED IN THE 1·8m (6ft) DIA AND 2·4m (8ft) DIA SECTION

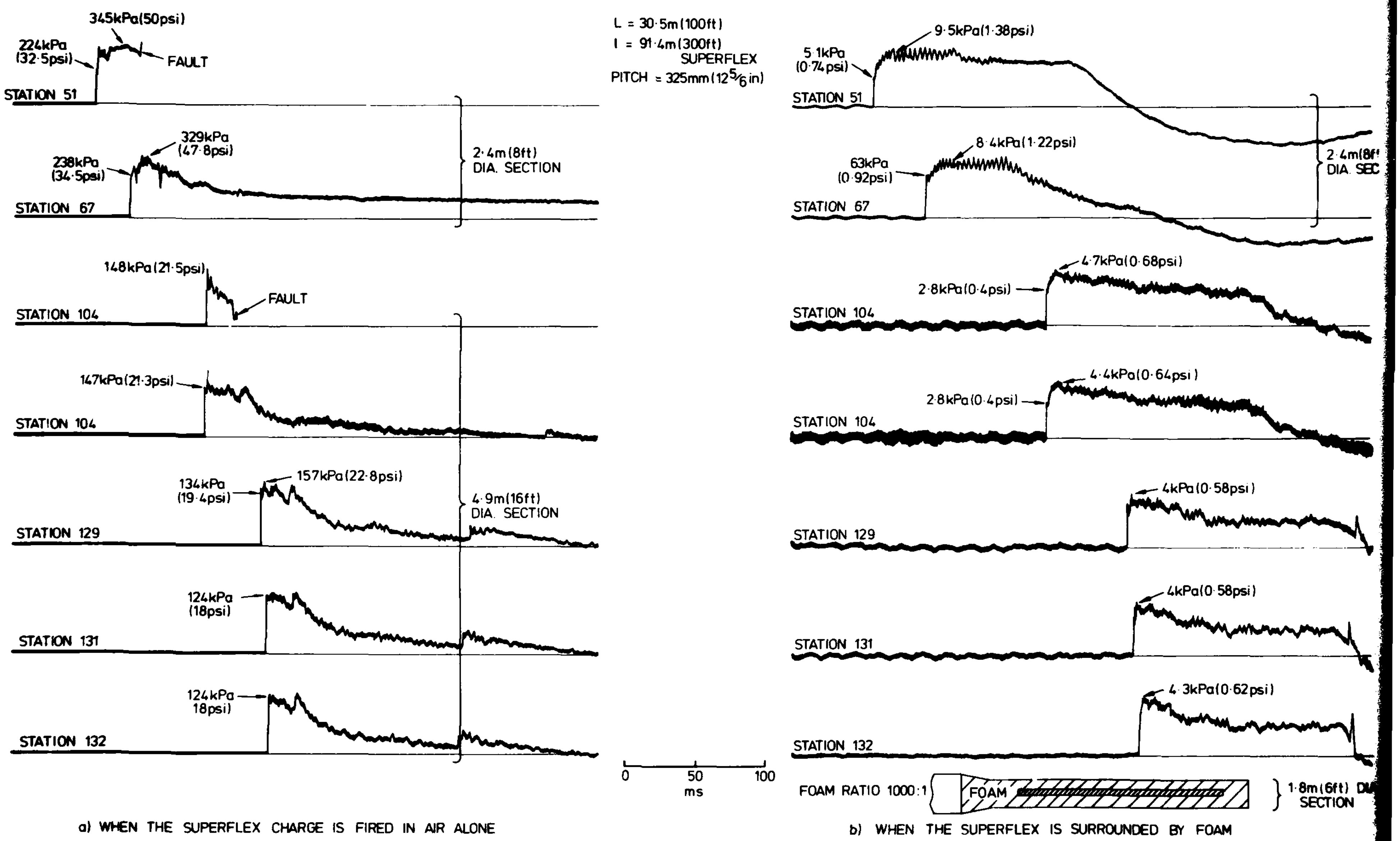


FIGURE 15. PROFILES OBTAINED IN THE 2·4m(8ft) DIA. AND 4·9m(16ft) DIA. SECTION

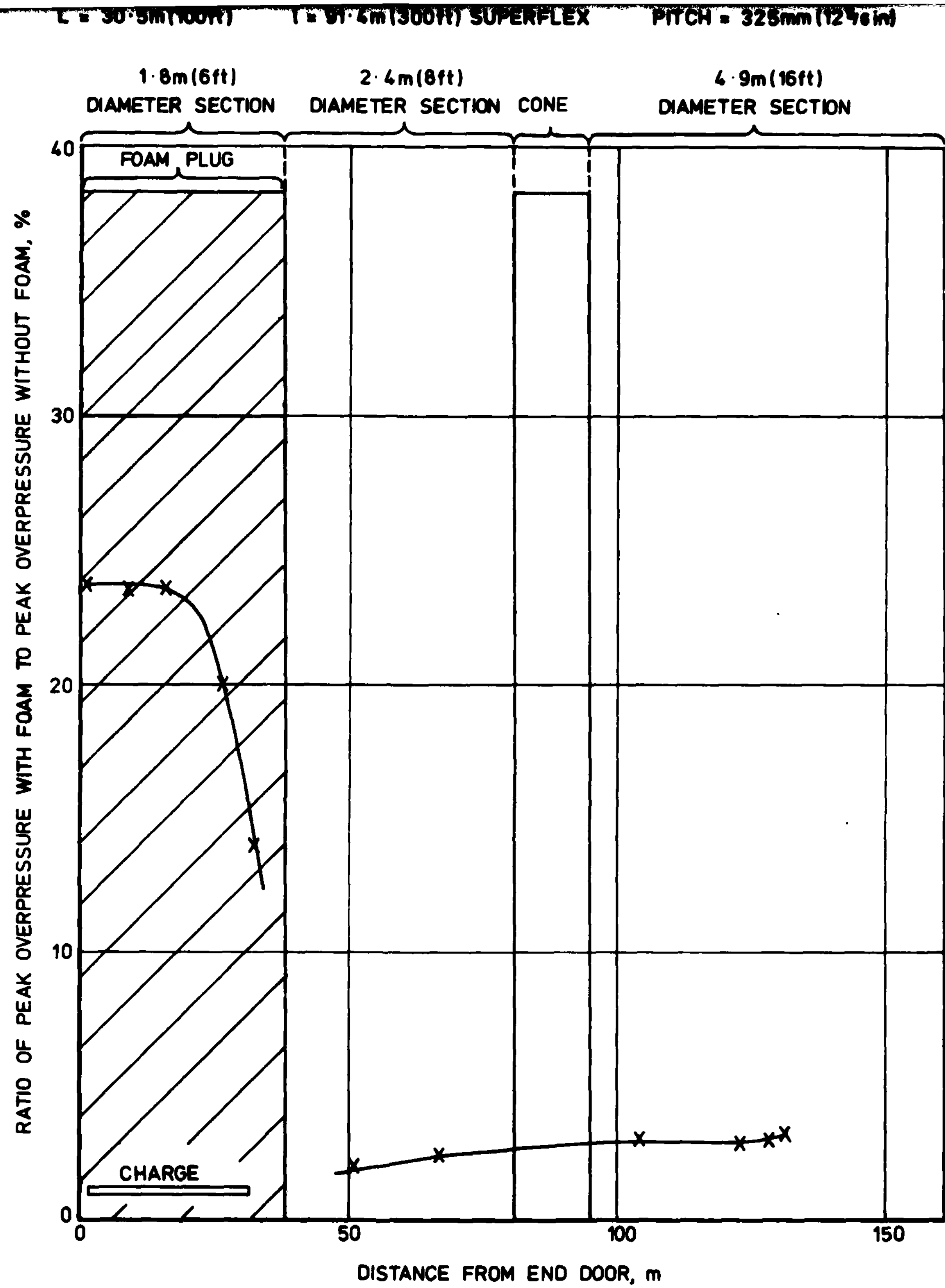


FIGURE 16. EFFECT OF AQUEOUS FOAM ON PRESSURE WHEN FIRING WITH THE CHARGE SURROUNDED BY FOAM COMPARED WITH FIRING THE SAME CHARGE WITHOUT FOAM

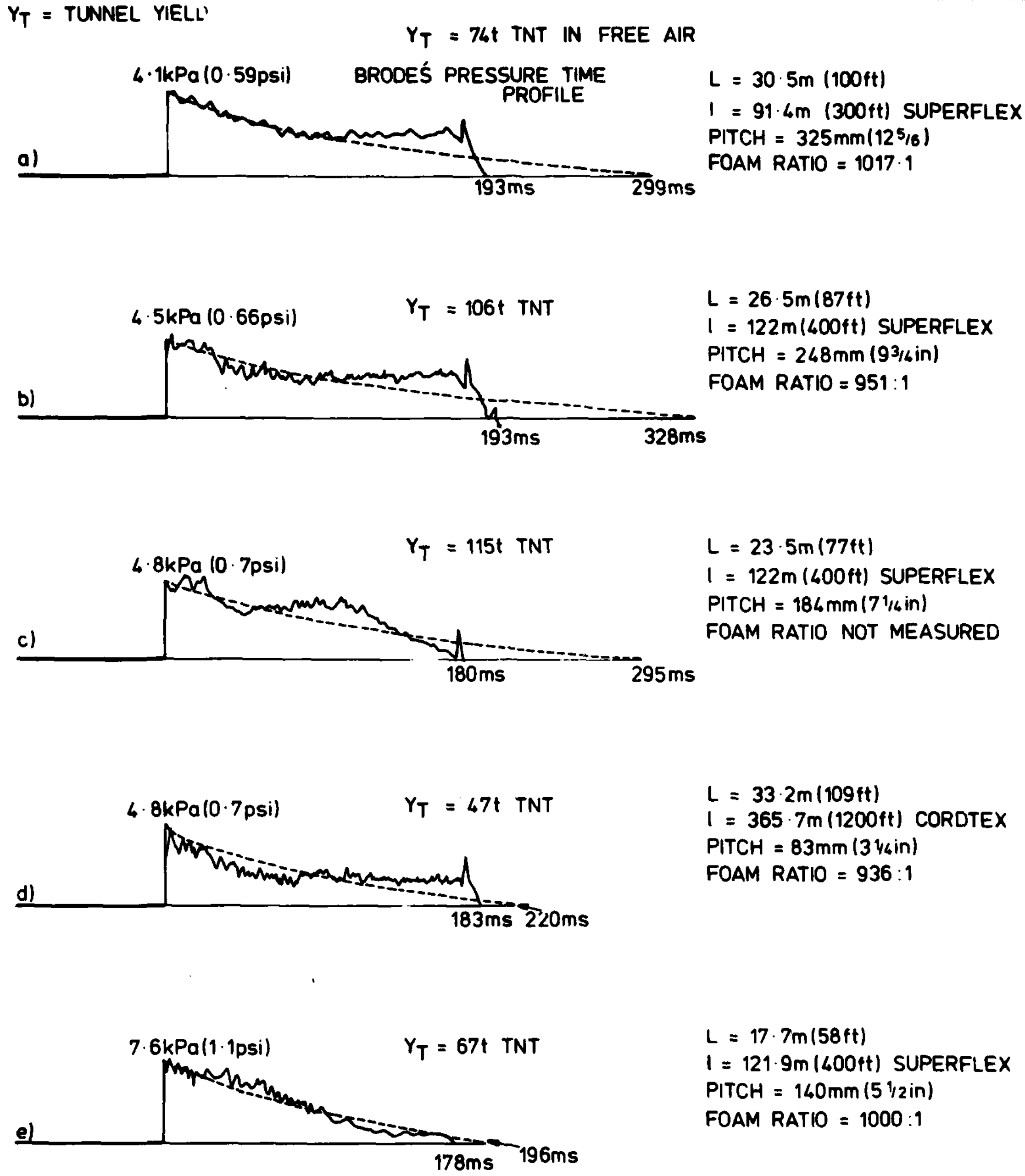


FIGURE 17 LOW PRESSURE LONG DURATION PRESSURE-TIME PROFILES OBTAINED IN THE 4·9m(16ft) DIA SECTION USING FOAM

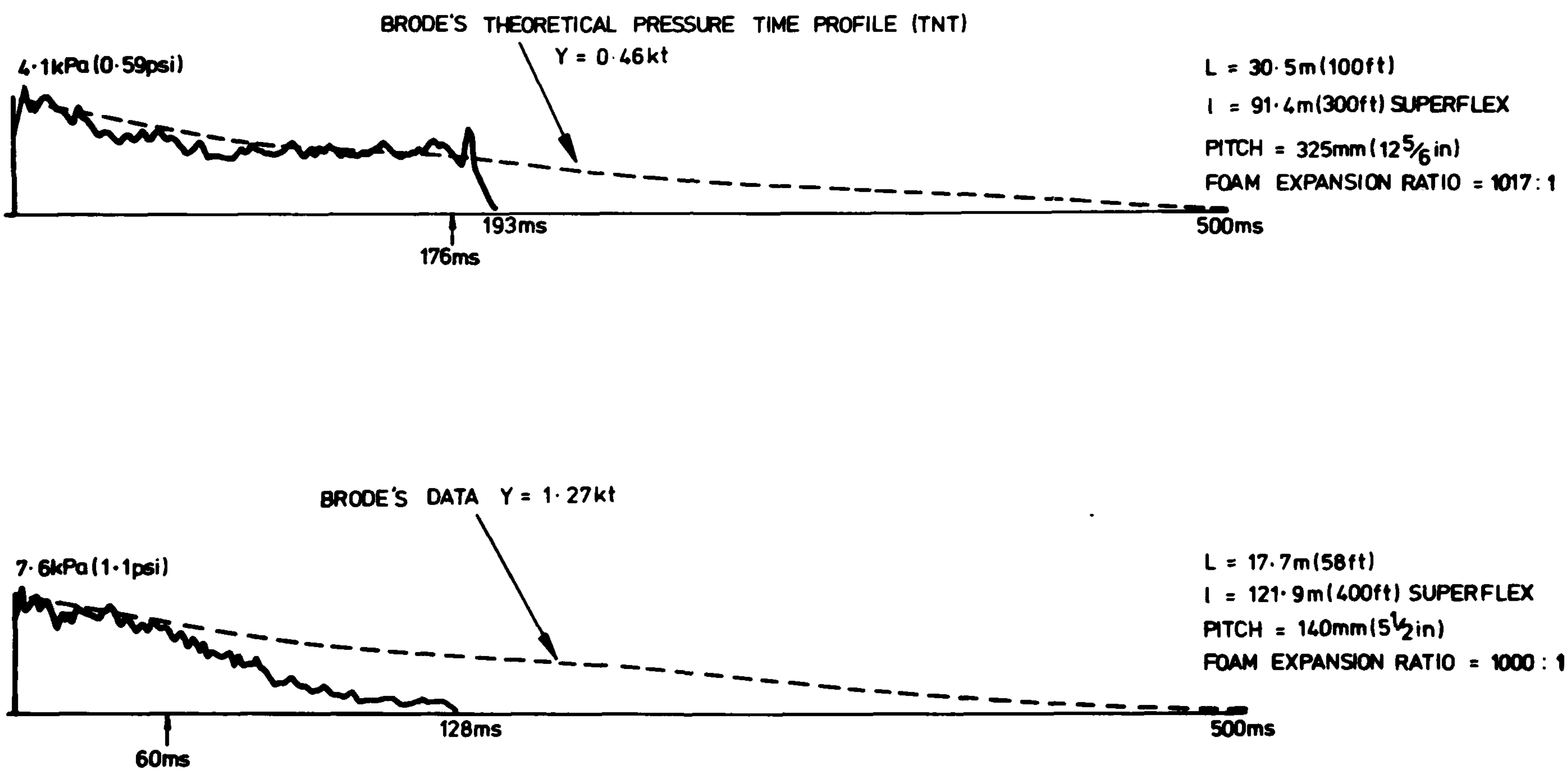


FIGURE 18. COMPARISON OF LOW PRESSURE TUNNEL PROFILES WITH TNT FIRED IN AIR

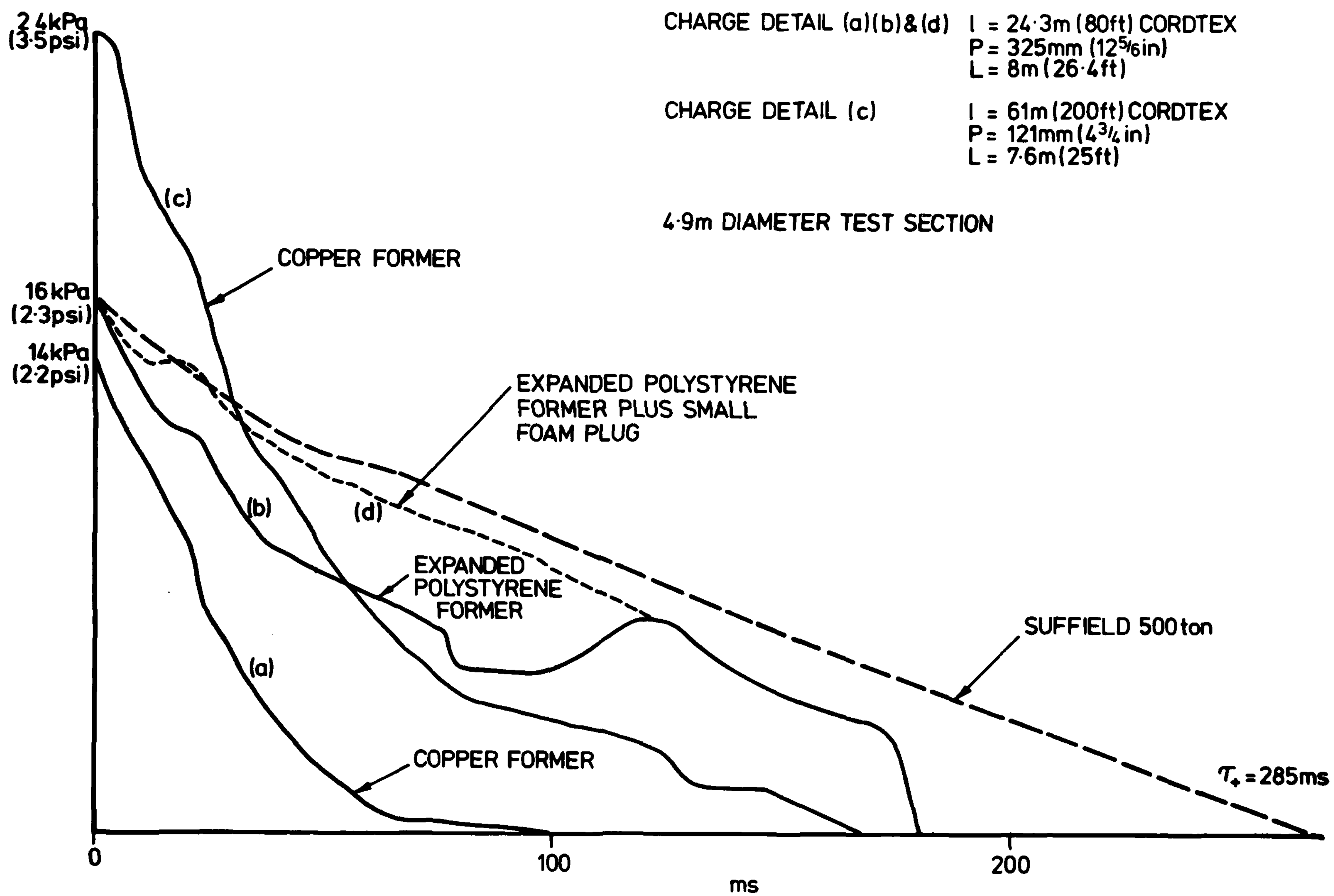


FIGURE 19. EFFECT ON THE PRESSURE-TIME PROFILE OF VARYING CHARGE GEOMETRY AND FORMER MATERIAL

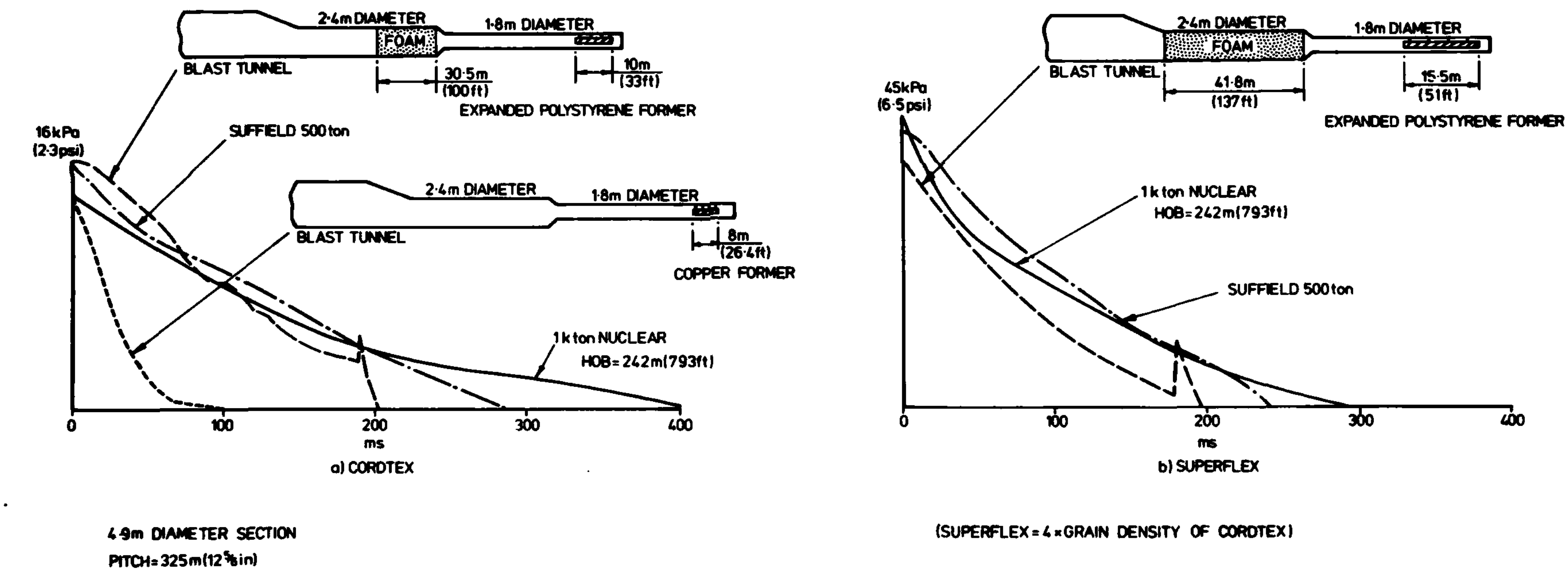


FIGURE 20. DIRECT COMPARISON OF TUNNEL PROFILES WITH THOSE FROM MULTITON AND NUCLEAR SHOTS

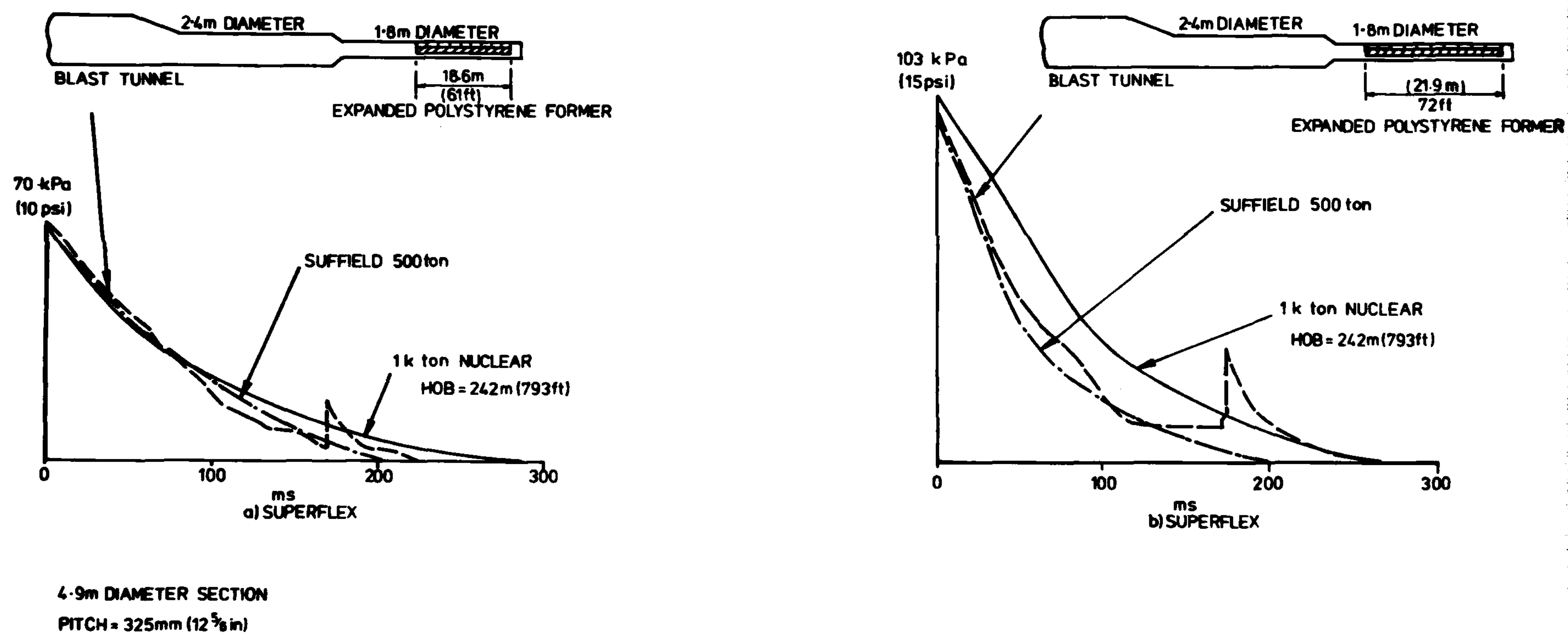


FIGURE 21. DIRECT COMPARISON OF TUNNEL PROFILES WITH THOSE FROM MULTITON AND NUCLEAR SHOTS

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Clare P M	-	-	March 1980	31	4

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Fuzes (ordnance)
Waveform generators

Abstract
The various techniques used to drive the Foulness multiton air blast simulator and obtain optimum performance are described.

These involve boosting the total energy release of the explosive driver using expanded polystyrene and at the same time, controlling the rate of release. The part played by aqueous foam in minimising irregularities in waveform also is described.

Some Metric and SI Unit Conversion Factors

(Based on DEF STAN 00-11/2 "Metric Units for Use by the Ministry of Defence", DS Met 5501 "AWRE Metric Guide" and other British Standards)

Quantity	Unit	Symbol	Conversion
Basic Units			
Length	metre	m	1 m = 3.2808 ft 1 ft = 0.3048 m
Mass	kilogram	kg	1 kg = 2.2046 lb 1 lb = 0.45359237 kg 1 ton = 1016.05 kg
Derived Units			
Force	newton	$N = kg\ m/s^2$	1 N = 0.2248 lbf 1 lbf = 4.44822 N
Work, Energy, Quantity of Heat	joule	J = N m	1 J = 0.737562 ft lbf 1 J = 9.47817×10^{-4} Btu 1 J = 2.38846×10^{-4} kcal 1 ft lbf = 1.35582 J 1 Btu = 1055.06 J 1 kcal = 4186.8 J
Power	watt	W = J/s	1 W = 0.238846 cal/s 1 cal/s = 4.1868 W
Electric Charge	coulomb	C = A s	-
Electric Potential	volt	V = W/A = J/C	-
Electrical Capacitance	farad	F = A s/V = C/V	-
Electric Resistance	ohm	Ω = V/A	-
Conductance	siemen	$S = 1\ \Omega^{-1}$	-
Magnetic Flux	weber	Wb = V s	-
Magnetic Flux Density	tesla	$T = Wb/m^2$	-
Inductance	henry	H = V s/A = Wb/A	-
Complex Derived Units			
Angular Velocity	radian per second	rad/s	1 rad/s = 0.159155 rev/s 1 rev/s = 6.28319 rad/s
Acceleration	metre per square second	m/s^2	1 m/s^2 = 3.28084 ft/s^2 1 ft/s^2 = 0.3048 m/s^2
Angular Acceleration	radian per square second	rad/s^2	-
Pressure	newton per square metre	N/m^2 = Pa	1 N/m^2 = 145.038×10^{-6} lbf/in^2 1 lbf/in^2 = 6.89476×10^3 N/m^2
	bar	bar = 10^5 N/m^2	- 1 in. Hg = 3386.39 N/m^2
Torque	newton metre	N m	1 N m = 0.737562 lbf ft 1 lbf ft = 1.35582 N m
Surface Tension	newton per metre	N/m	1 N/m = 0.0685 lbf/ft 1 lbf/ft = 14.5939 N/m
Dynamic Viscosity	newton second per square metre	$N\ s/m^2$	1 $N\ s/m^2$ = 0.0208854 $lbf\ s/ft^2$ 1 $lbf\ s/ft^2$ = 47.8803 $N\ s/m^2$
Kinematic Viscosity	square metre per second	m^2/s	1 m^2/s = 10.7639 ft^2/s 1 ft^2/s = 0.0929 m^2/s
Thermal Conductivity	watt per metre kelvin	W/m K	-
Odd Units*			
Radioactivity	becquerel	Bq	1 Bq = 2.7027×10^{-11} Ci 1 Ci = 3.700×10^{10} Bq
Absorbed Dose	gray	Gy	1 Gy = 100 rad 1 rad = 0.01 Gy
Dose Equivalent	sievert	Sv	1 Sv = 100 rem 1 rem = 0.01 Sv
Exposure	coulomb per kilogram	C/kg	1 C/kg = 3876 R 1 R = 2.58×10^{-4} C/kg
Rate of Leak (Vacuum Systems)	millibar litre per second	mb l/s	1 mb = 0.750062 torr 1 torr = 1.33322 mb

*These terms are recognised terms within the metric system.